Effect of Micro Electrical Discharge Machining Process Conditions on Tool Wear Characteristics: Results of an Analytic Study

Puthumana, Govindan; P., Rajeev

Published in:
Proceedings of the National Conference on Futuristic Advancements in Mechanical Engineering (Fame 2K16)

Publication date:
2016

Document Version
Peer reviewed version

Effect of Micro Electrical Discharge Machining Process Conditions on Tool Wear Characteristics: Results of an Analytic Study

Dr. Govindan Puthumana[1*] and Dr. Rajeev P[2].

[1]*Dept. of Mechanical Engineering, Technical University of Denmark, Denmark-2800*

[2]*Dept. of Mechanical Engineering, College of Engineering Thalassery, Kerala, India*

**Corresponding author: govindanp2002@gmail.com*

***Abstract*— Micro electrical discharge machining is one of the established techniques to manufacture high aspect ratio features on electrically conductive materials. This paper presents the results and inferences of an analytical study for estimating the effect of process conditions on tool electrode wear characteristics in micro-EDM process. A new approach with two novel factors anticipated to directly control the material removal mechanism from the tool electrode are proposed; using discharge energy factor (DE_f) and dielectric flushing factor (DF_f). The results showed that the correlation between the tool wear rate (TWR) and the factors is poor. Thus, individual effects of each factor on TWR are analyzed. The factors selected for the study of individual effects are pulse on-time, discharge peak current, gap voltage and gap flushing pressure. The tool wear rate decreases linearly with an increase in the pulse on-time. A maximum increase of 28.57% has been observed between peak current of 1 and 1.5 A.TWR decreases with an increase in pressure by 19.6%.**

Keywords*— *Micro-EDM, tool wear rate, discharge energy factor, dielectric flushing factor, correlation, and factor effect.

I. INTRODUCTION

Electrical discharge machining (EDM) is a prevalent unconventional machining process employed in industry for machining different types of electrically conductive materials. It is extensively used for machining of complex contours and high aspect ratio features. Micro electrical discharge machining is an adaptation of the EDM to machine complex micro-features with high precision. Tool electrode wear is one of the important challenges that impede achievement of high precision in machining of different geometries at all process conditions in EDM [1] as well as micro-EDM [2] processes. There have been several investigations on the phenomenon of tool electrode wear in micro-EDM process.

II .LITERATUREREVIEW

Uhlmann et al. [3] have analyzed the phenomenon of removal of material from the tool electrodes after applying CVD diamond coatings on them. Further, the same research group has investigated the behavior of different tool electrode materials such as copper, cemented carbide and copper tungsten for optimum performance of the micro-EDM process [4]. In another similar investigation on performance of different tool electrode materials; copper-tungsten, silver-tungsten and tungsten carbide, Jahan et al. [5] observed that copper-tungsten tools helps yield the highest material removal rate, and, at the same time, silver-tungsten tools generates the best surface finish of the order of nanometers in magnitudes of R_a. Yu et al. [6] proposed dry electrical discharge machining for cutting cemented carbide. The results of the study showed that a lower tool wear ratio than that in oil electrical discharge machining can be achieved. The tool electrode wear in micro-EDM drilling and effect of different parameters on the wear characteristics was investigated by Pham et al. in 2007 [7]. Dielectric flushing was recognized as one of the key issues limiting precision in the micro-EDM process. Additionally, the variation in the shape of the tool electrode during machining of high aspect ratio features generates difficulty in estimation of the tool electrode wear [8]. Recently, an attempt to use fuzzy techniques and response surface methodology using central composite design was demonstrated by Tiwary et al. in 2014 [9]. Analysis of closeness coefficients has been applied to classify the dominating parameters. Therefore, in this paper, an extended altered discussion on the tool wear characteristics under the effect of micro-EDM process conditions is presented. Since the material removal from the tool electrode surfaces is mainly influenced by the energy of each discharge causing work piece material removal, an attempt has been made to evaluate whether any correlation exist. Similarly, a degree of correlation between debris flushing and tool wear is estimated. The influence of energy is ascertained by considering the energy factor (DE_f) and flushing factor by flushing factor (DF_f). Furthermore, the individual effects of each micro-EDM governing factor are analyzed in this work.

II. METHODOLOGY

In the present work the results and inferences of an analytical study for estimating the effect of process conditions on tool electrode wear characteristics in micro-EDM process is presented. A new approach with two novel factors anticipated to directly control the material removal mechanism from the tool electrode are proposed; using discharge energy factor (DE_f) and dielectric flushing factor (DF_f). The results showed that the correlation between the tool wear rate (TWR) and the factors is poor. Thus, individual effects of each factor on TWR are analyzed. The factors selected for the study of individual effects are pulse on-time, discharge peak current, gap voltage and gap flushing pressure.

III . RESULTS AND ANALYSIS

A. *Correlation between discharge energy factor (DE_f) and tool wear rate*

In micro-EDM process, discrete electrical discharges occur in the inter-electrode gap filled with an insulating dielectric fluid. The gap voltage, discharge current and the pulse duration influence the energy of each spark. The kinetic energy of the electrons is transformed into heat energy of the plasma, and is indicated by the temperature of the plasma. The discharge energy in micro-EDM is mathematically expressed as

$$DE_f = V \times I \times T_{on} \quad (1)$$

where, V is the gap voltage, I is the discharge current and $T_{on}$is the pulse on-time. The relationship between the tool wear rate (TWR) and the calculated values of DE_f is shown in Fig.1. As can be observed from the plot, there is a large scatter in the values of tool wear rate. The discharge energy varies between 60 and 1080 µJ. Between the energy levels of 600 and 1000 µJ, the scatter in the magnitude of TWR is the largest, and at the same time the maximum TWR of 3.87×10^{-3} mm^3/min has been observed at an energy of 840 µJ. The maximum variation in the magnitude of tool wear rate is close to 70%. Furthermore, the overall average of the tool wear rate is 2.48×10^{-3}mm^3/min.

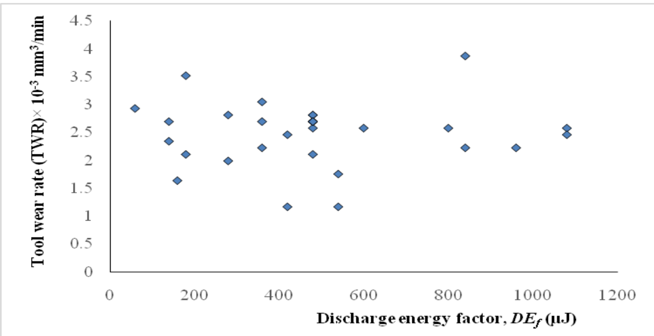

Fig. 1 Correlation between TWR $\times 10^{-3}$ (mm^3/min) and the discharge energy factor DE_f (µJ)

B. *Correlation between dielectric flushing factor (DF_f) and TWR*

The debris particles are flushed away from the discharge gap by the dielectric fluid flow. If the flushing mechanism is not effective, a portion of the condensed material may remain in the liquid dielectric bubbles that lead to instability of the discharge phenomena in micro-EDM process. Thus, a factor dielectric flushing factor (DF_f) which is of the magnitude of the flushing pressure is considered in this study. Fig. 2 shows a relationship between tool electrode wear rate and the dielectric flushing factor. The dielectric flushing factor varies between 0.15 and 0.35 kg/cm^2. At dielectric flushing factors of 0.2, 0.25 and 0.3, the variations in the tool wear rate are 139%, 136% and 200%. Though, a direct relationship between tool wear rate and dielectric flushing factor is not obtained, the DF_f is an indicator of the effect of dielectric flushing on the material removal from the tool electrode surfaces. At dielectric flushing factors of 0.2, 0.25 and 0.3, the tool electrode wear rate values are stable around the values of 2.5×10^{-3} mm^3/min, 2.7×10^{-3} mm^3/min and 2.1×10^{-3} mm^3/min. Therefore, as the DF_f increases by 20%, the average tool electrode wear rate decreases sharply by 22%. Since the correlations between tool electrode wear rate and the discharge energy factor as well as the dielectric flushing factor cannot be accurately established, further independent analysis on the effect of each of the individual factor is necessary. The individual effects of factors would help evaluate the rate of variations of the TWR.

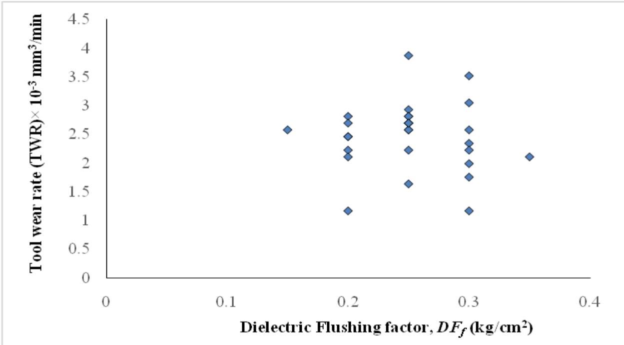

Fig. 2 Correlation between tool wear rate (TWR) and dielectric flushing factor, DF_f

C. *Individual factor effects on TWR*

The effects of individual factors (pulse on time, peak current, gap voltage and flushing pressure) are studied to understand the relative importance of these factors. The range of factors chosen for this investigation and a schematic of the process is shown in Fig. 3.

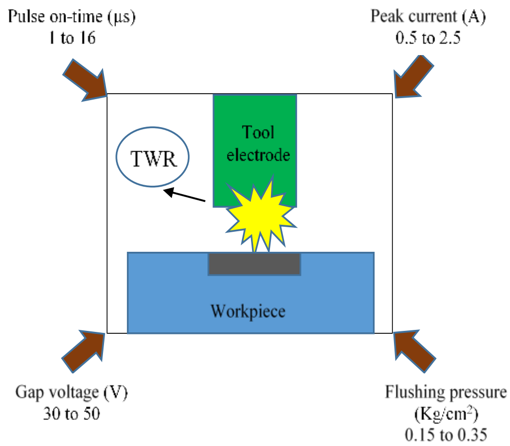

Fig. 3 Range of factors selected to estimate the individual effect on TWR

Table 1 Details of the basic experimental investigation; work piece, tool and machining process [9]

Workpiece (positive polarity)	Tool (negative polarity)	Geometrical dimensions of tool and machining strategy	Relevant individual factor effects for micro-ED drilling
Alpha-beta titanium super alloy	Brass	Tool electrode Ø 300 µm, micro-EDM drilling	Effect of pulse on-time Effect of peak current Effect of gap voltage Effect of flushing pressure
Al : 6%	Cu: 65%		
Fe: 0.25%	Zn: 34%		
O: 0.2%	Pb: 0.15%		
Ti: 89.5%	Fe: 0.05%		
V: 4%	--------		

The details of the basic experimental investigation [9] are shown in Table 1. The parameters influencing both discharge energy as well as dielectric flushing have a great importance in the evaluation of the tool electrode wear [10]. The efforts to model the micro-EDM process mechanisms involve the representation of the tool wear as a function of these significant input parameters. These factor effects are discussed in order to identify the relative importance of the factors on the tool wear mechanisms and the trends of the effects.

D. Effect of pulse on time on tool wear rate (TWR)

The individual effect of pulse on-time on the TWR is presented in Fig. 4. The corresponding quantifiable assessment of this effect with an increase in the pulse on-time is shown in Table 2. It is evident that the TWR decreases with an increase in the pulse on-time in micro-EDM process. The maximum decrease of 13.72% has been observed between a pulse on-time of 8 and 12 µs.

Table 2. Effect of pulse on-time on TWR

Tool wear rate (mm^3/min) → Pulse on-time (µs) ↓	Effect of pulse on-time on the TWR
1	------
4	10.34% ↓
8	1.90% ↓
12	13.72% ↓
16	1.00% ↑
↑ -increase	↓ -decrease

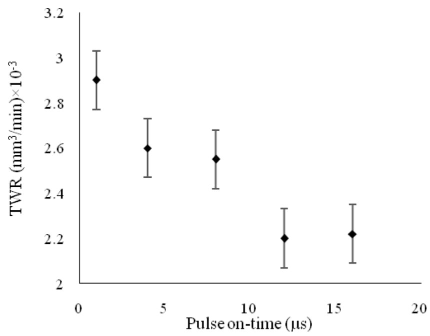

Fig. 4 Individual factor effect of pulse on time on TWR

4.2 Effect of peak current on the tool wear rate (TWR)

Table 3. Effect of peak current on TWR

Tool wear rate (mm^3/min) → Peak current (A) ↓	Effect of peak current on TWR
0.5	------
1.0	23.80% ↑
1.5	28.57% ↓
2.0	1.00% ↓
2.5	2.90% ↓
↑ -increase	-decrease ↓

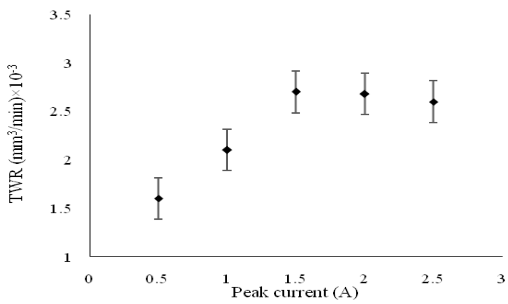

Fig. 5 Individual factor effect of peak current on TWR

Fig. 5 shows the single effect of peak current on the TWR. The corresponding quantifiable assessment of this effect with an increase in the peak current is shown in Table 3. It is evident that the TWR increases with an increase in the peak current in micro-EDM process upto a 1.5 A. This could be because of an increase in the DE_f. The maximum increase has been observed between peak current of 1 and 1.5 A.

4.3 Effect of gap voltage on the tool wear rate (TWR)

An overall decrease in the TWR by 4% is evident, see Fig. 6. The corresponding quantifiable assessment of this effect with an increase in the gap voltage is shown in Table 4. As the voltage increases, the TWR fluctuates significantly. This could be attributed to the variations in the discharge gap with a change in the gap voltage in micro-EDM. The extreme deviation of 12.17% has been found between 45 and 50 V.

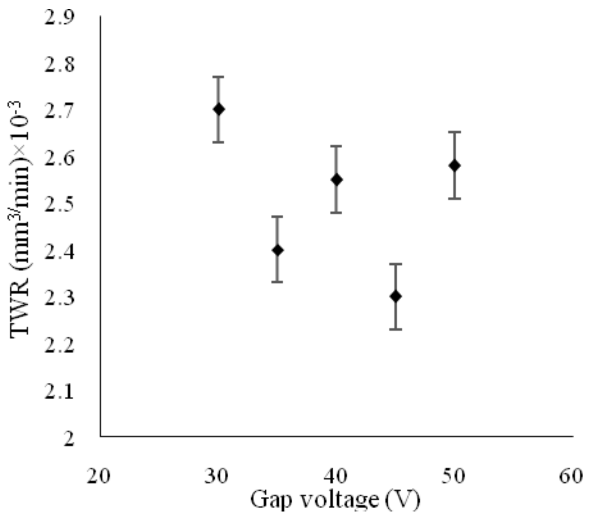

Fig. 6 Individual factor effect of gap voltage on TWR

Table 4. Effect of gap voltage on TWR

Tool wear rate (mm^3/min) → Gap voltage (V) ↓	Effect of gap voltage on TWR
30	------
35	11.00% ↓
40	6.25% ↑
45	9.80% ↓
50	12.17% ↑
↑ -increase	↓ -decrease

4.4 Effect of flushing pressure on Tool wear rate (TWR)

The influence of pressure of flushing on the tool wear rate is presented in Fig. 7. The corresponding quantifiable assessment of this effect with an increase in the pressure is shown in Table 5. It is evident that the TWR decreases with an increase in pressure by 19.6%. However, between 0.2 to 0.25 kg/cm^2, an increase in TWR by 17.39% is observed. This could be correlated to the results of DF_f presented in Fig. 2. As the pressure increases from 0.25 to 0.30 kg/cm^2, a rapid decrease in TWR by 12.90% is observed.

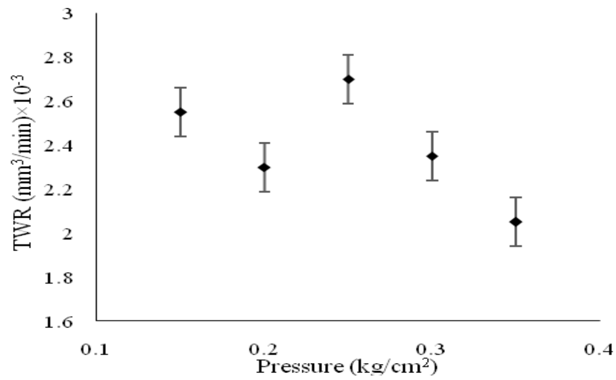

Fig. 7 Individual factor effect of pressure on TWR

Table 5. Effect of pressure on TWR

Tool wear rate (mm^3/min) → Pressure (kg/cm^2) ↓	Effect of pressure on TWR
0.15	------
0.20	9.80% ↓
0.25	17.39% ↑
0.30	12.90% ↓
0.35	12.76% ↓
↑ -increase	↓ -decrease

IV. CONCLUSIONS

The results of an analytic study signifying the effect of micro-electrical discharge machining processing conditions on the characteristics of the tool electrode wear is presented in this paper. The following conclusions can be drawn from this study:

- An attempt to establish the correlation between process conditions and tool wear rate (TWR) in micro-EDM through an approach using two novel factors; discharge energy factor (DE_f) and dielectric flushing factor (DF_f) is implemented in this work. However, the results showed poor correlation between TWR, DE_f and DF_f.
- The tool wear rate decreases linearly with an increase in the pulse on-time. The maximum decrease of 13.72% has been observed between a pulse on-time of 8 and 12 µs.
- TWR increases with an increase in the peak current in micro-EDM process upto a 1.5 A.A maximum increase of 28.57% has been observed between peak current of 1 and 1.5 A.
- As the voltage increases, the TWR fluctuates significantly. This could be attributed to the

variations in the discharge gap with a change in the gap voltage in micro-EDM.

- TWR decreases with an increase in pressure by 19.6%. However, between 0.2 to 0.25 kg/cm^2, an increase in TWR by 17.39% is observed.

ACKNOWLEDGEMENTS

The author would like to acknowledge the support from H.C. Ørsted COFUND postdoc fellowship. The author would also like to thankfully acknowledge Prof. Dr. Rajeev P (COE,Thalassery), Prof. Sailesh Raju (MED, GCE, Kannur) and Prof. Dr. Gireesan K. K. (GCE, Kannur) for their kind support and invaluable encouragement without which joining for this prestigious research program would not have been possible.

REFERENCES

[1] Ho, K. H. and Newman, S. T. (2003), State of the art electrical discharge machining, *International Journal of Machine Tools and Manufacture*, v43, n13, pp. 1287-1300.

[2] Jahan, M. P., Rahman, M. and Wong, Y. S. (2011), Study on the nano-powder-mixed sinking and millingmicro-EDM of WC-Co, *International Journal of Advanced Manufacturing Technology*, v53, n1, pp. 167-180.

[3]Uhlmann E, Rosiwal S, Bayerlein K, Röhner M (2010) Influence ofgrain size on the wear behavior of CVD diamond coatings in micro-EDM. *International Journal of Advanced Manufacturing Technology*, 47:919–922.

[4]Uhlmann E, Roehner M (2008) Investigations on reduction of toolelectrode wear in micro-EDM using novel electrode materials. *CIRP J ManufSciTechnol* 1:92–96.

[5] Jahan MP, Wong YS, Rahman M (2009) A study on the fine-finish die-sinking micro-EDM of tungsten carbide using different electrode materials. *J Mater Process Technol* 209:3956–3967.

[6] Yu ZB, Jun T. and Masanori K (2004) Dry electrical discharge machining of cemented carbide,*J Mater Process Technol* 149:353–357.

[7] Pham, D. T., Ivanov, A., Bigot, S., Popov, K. and Dimov, S. (2007), An investigation of tube and rod electrode wear in micro EDM drilling, *International Journal of Advanced Manufacturing Technology*, v33, n1, pp. 103-109.

[8] Bigot S, Ivanov A, Popov K (2005) A study of the micro EDMelectrode wear. In: *Proceedings of the 1st International Conference on Multi-Material Micro Manufacture* (4M 2005), Karlsruhe, Germany, June/July 2005, pp 355–358.

[9] Tiwary, A. P., Pradhan, B. B. and Bhattacharyya, B. (2014), Application of multi-criteria decision-making methods for selection of micro-EDM process parameters, *International Journal of Advanced Manufacturing Technology*, v2, n3, pp. 251-258.

[10] Zhang, L., Jia, Z., Wang, F. and Liu, W. (2010), A hybrid model using supporting vector machine and multi-objective genetic algorithm for processing parameters optimization in micro-EDM, *International Journal of Advanced Manufacturing Technology*, v51, n5, pp.575-586.